DIFFUSE IONIZED GAS IN RCW 108

J.C. CERSOSIMO*

Instituto Argentino de Radioastronomía
* Fellow of the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) of Argentina

RESUMEN:

Se observó la línea 166 α en dirección de la región HII extendida RCW 108, con una resolución en velocidad de 2 km/s. La velocidad central de la línea es de -20 km/s. La región también ha sido observada en el continuo en la frecuencia de 1420 MHz. Desde estas observaciones se deducen los parámetros físicos del gas ionizado. Dichos parámetros sugieren que la línea se forma en un gas ionizado difuso el cual tiene una densidad electrónica de 11 cm^{-3} y una temperatura electrónica de aproximadamente 4600°K.

INTRODUCTION

The more important stellar members of the association Ara OB1 are the O stars HD 150135 and HD 150136, which are embedded in the low brightness emission nebulae RCW 108 (Whiteoak, 1963; Rodgers et al. 1960). Observations of the radio continuum emission at 5 GHz in this direction show an extended HII region (Haynes et al. 1979) near the stars (15 minutes of arc) with a peak centered in the direction $l = 336\overset{\circ}{.}5$, $b = -1\overset{\circ}{.}5$. Embedded in it is an infrared source (Frogel et al. 1974) with associated strong OH 1667 Mhz absorption at a velocity of -24 km/s (Caswell and Robinson, 1974) and formaldehyde absorption at -22.4 km/s (Whiteoak et al., 1974). On the other hand the H109 α line has been detected by Wilson et al. (1970) with a beam of 4' arc and a velocity resolution of 6 km/s, at some position at a velocity of -25 km/s.

To understand the later stages of evolution of HII regions it is important to know the physical conditions in those regions where moderately dense gas is present, as for example in the nebulae RCW 108. For these regions radio recombination lines provide an independent estimate of electron temperature and velocities. To this end emission in the H166 α line has been searched for in the direction of this nebulae. The nature of the region where the line is formed is discussed. Furthermore, in this paper we present radio continuum observations of the region at 1.4 Ghz.

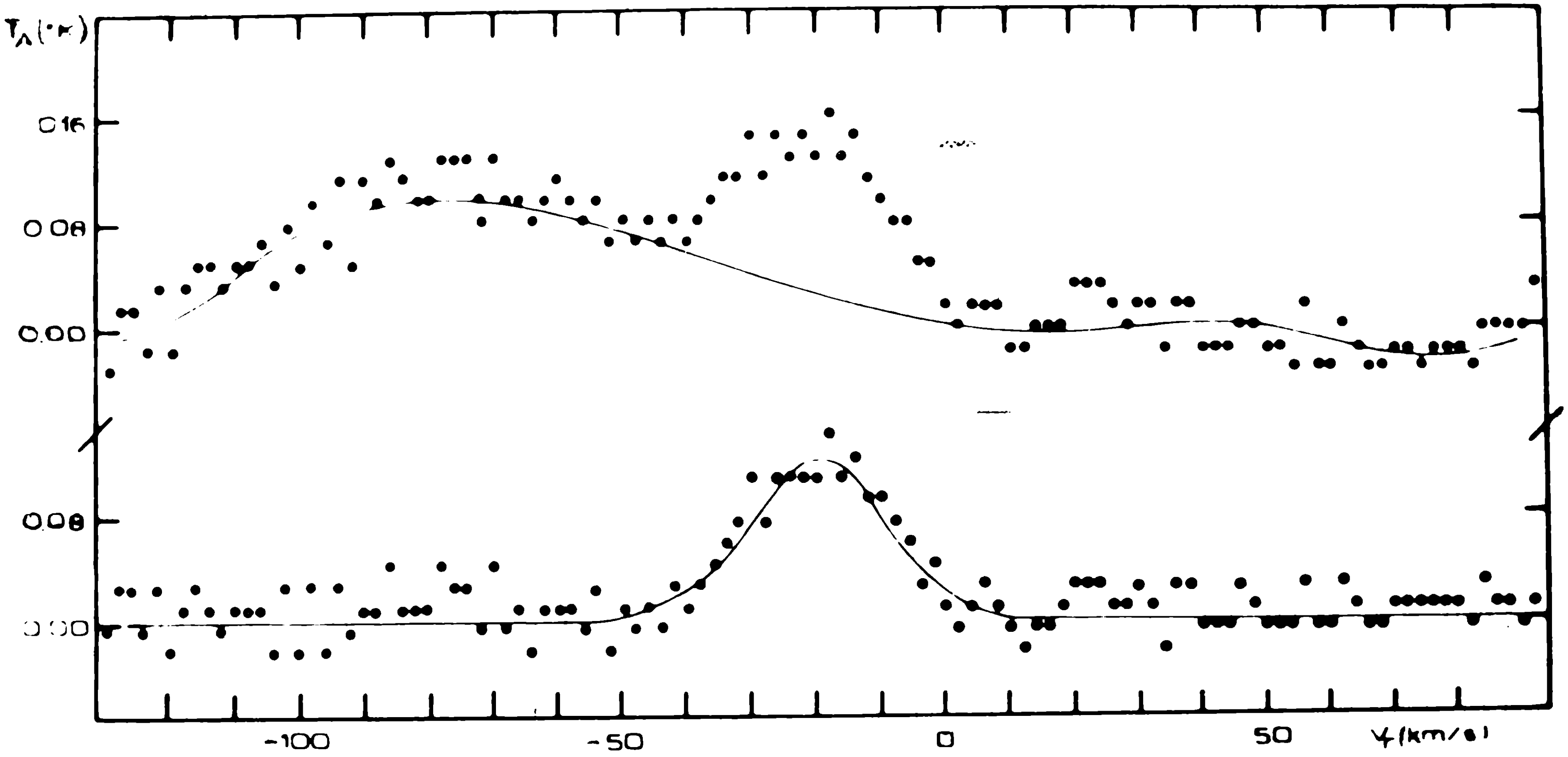

Figure 1: Upper figure (a): The observed H166α line in the direction l = 336°5 b = 1°5. The full line represents the seven degree polinomial that fits the base line where no line emission was detected.

Lower figure (b): The same profile with the baseline removed. The full line indicates a gaussian fit to the emission profile.

OBSERVATIONS

The observations were made with the 30 m-diameter antenna of the Instituto Argentino de Radioastronomía (IAR), which at 1.4 Ghz has a half-power beamwidth (HPBW) of 34 arc.min. The line data were taken at α (1981) = $16^h\ 38^m\!.7$, δ (1981) = $-48°\!.85$ (l = $336°\!.5$, b = $-1°\!.5$) where the H109α line has been detected (Wilson et al., 1970). The receiver used consists of a room temperature parametric amplifier and 112 channel filter bank. Observations were made in the frequency switching mode. The system noise temperature was about 83 K on cold sky and the velocity resolution of the filter bank was 2 km/s. The profile obtained is shown in Figure 1a; the baseline shown as a solid line in this figure has been calculated by fitting a seven degree polynomial to the channels where no line emission occurs. The result of subtracting the baseline fit is shown in Figure 1b.

The region $240° < \alpha < 249°$, $-55° < \delta < -43°$ was observed in the continuum at 1.4 Ghz with a bandwith of 40 Mhz. A filter of bandwith of 2 Mhz centered on 1420.4057 Mhz was used for stopping the galactic neutral hydrogen emission. The receiver was operated in the Dicke switched mode with a gain modulator set to balance the system off the galactic plane in b = $-5°$. Constant right ascension scans were made with a velocity of the antenna of about 10°/minute, each $0°\!.25$ in right ascension. The receiver for continuum observations had a basic integration time of 0.7 seconds so that data points were spaced $0°\!.13$ in declination; the observations are shown in Figure 2.

RESULTS AND DISCUSSION

a) Electron density

The continuum antenna temperature obtained for the region from the continuum observations is 5 ± 0.75 supposing that this continuum temperature is emitted at some position where the line is formed. The rest of the continuum is considered to be composed by contributions from foreground and background emission (see Figure 2). The continuum antenna temperature was estimated calculating an upper and lower limit by fitting a curve baseline and a straight baseline to the points out of the region. Furthermore, the source is considered thermal (Shaver et al., 1970). This temperature has been used to calculate the electron density and emission measure (EM). A sphere of constant electron density and temperature with diameter of 14 pc. at a distance of 1.3 kpc. (Herbst et al., 1977) has been assumed. Whith this model a density $\langle N_e^2 \rangle^{1/2} = 11$ cm^{-3} and an EM of 2400 pc cm^{-6} are obtained assuming an electron temperature of 5000 K.

b) Electron temperature

The electron temperature was deduced using the line-to-continuum ratio technique, supposing that the line was formed under conditions of local thermodycanic equilibrium (LTE) and that the He/H abundance

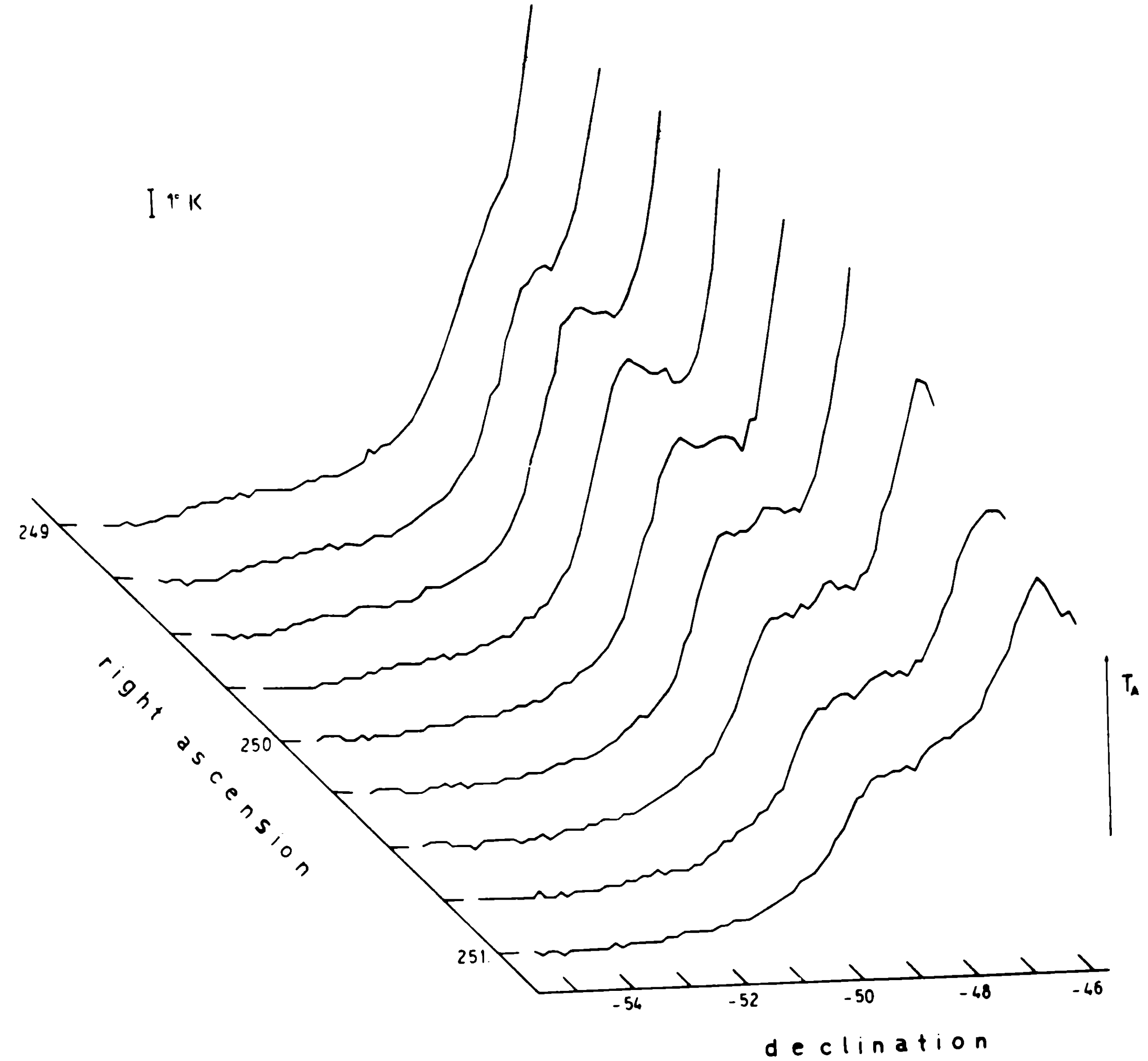

Figure 2: Three dimensional plot of the continuum scans made in the region

ratio is 0.1. The line-to-continuum ratio is 2.93 Khz which corresponds to an LTE electron temperature $T_e^* = 4600 \pm 1000$ K. The values of T_e^* and EM are in a good accord with those obtained by Pedlar (1980) for extended low-brightness HII regions. Furthermore, including our value of T_e^* in the plot of Figure 7 of Pedlar (1980) it can be seen that it is also consistent with the gradient of electron temperature with distance to Galactic Center of 310 K kpc^{-1} obtained by Churchwell et al. (1978).

c) Thermodynamic equilibrium

The possibility that departures from LTE are present is investigated through the expression for the ratio of real electron temperature, T_e, to the electron temperature T_e obtained supposing LTE

$$\frac{T_e}{T_e^*} = \left[b_n \left(1 + \frac{\tau c}{2} \frac{kT_e}{h\nu} \frac{d \ln b_n}{dn} \Delta n \right) \right]^{0.87}$$

In this equation τc is the optical depth for continuum radiation, Δn is the size of the electron transition between the levels $n+\Delta n$ and n, b_n are the departure coefficients for the atomic level n. The other constants have their usual meanings. Using the b_n coefficients given by Brocklehurst (1970) a value $T_e/T_e^* = 1$ is obtained for $N_e = 10\ cm^{-3}$. There are two ways for explaining these results: i) as a compensation between stimulated emission in the low density outer regions by the continuum radiation of the inner core regions (Brocklehurst and Seaton, 1972; Seaton, 1974) and pressure broadening which may be present in the nebulae. ii) That the effects of departure from LTE are negligible in our observations and furthermore that pressure broadening is not significant. The latter alternative seems more likely. Pressure broadening does not play a dominant role because the $\Delta\nu_S/\Delta\nu_D$ ratio (Griem, 1967) is unimportant when the density $N_e < 10^3\ cm^{-3}$ for n> 150, where $\Delta\nu_S$ is the stark (electron collision) broadened line half-power width, which in its far wings can be approximated by a lorentzian line shape, and $\Delta\nu_D$ is the Doppler half-power width. For observations at low frequency and large beamwidth the large area of the outer low density region dominates in recombination line emission over any smaller region of high density because of a combination of beam dilution and optical depht effects. Hence the T_e^* obtained under the LTE asumption should be a good approximation to the actual electron temperature.

d) Structure and Dynamics

The parameters obtained for the ionized gas at 1.4 Ghz are shown in Table 1 where they are compared with those obtained by Wilson et al. (1970) at 5 Ghz. The comparison between parameters from the two frequencies suggests that the zone consists of a compact region with high density ($\simeq$ 3000 cm^{-3}) and high temperature ($\simeq$ 9700 K) and an extended region with low density ($\simeq$ 11 cm^{-3}) and low temperature ($\simeq$ 4600 K). The more dense region is presumably embedded within the colder diffuse gas which would be ionized by ultraviolet radiation from early type stars of the young cluster NGC 6193. A similar interaction between stars and diffuse gas is present in small HII regions as those described by Jackson and Kerr (1975). In our case supposing two stars of 45 solar masses, we obtain the continuum photon flux required to ionize the nebulae $N_c > 5.5\times10^{49}\ s^{-1}$. In the region observed we obtained $N_c \geq 1.9\times10^{49}\ s^{-1}$ from our data. It was calculated using the relation (Mezger, 1973)

$$\left(\frac{N_c}{s^{-1}}\right) \geq 5.0457 \times 10^{46} \left(\frac{T_e}{K}\right)^{-0.8} \left(\frac{U}{pc\ cm^{-2}}\right)^{3}$$

where U is the excitation parameter (Hjellming, 1968), and the electron temperature was assumed to be $5x10^3$ K.

The radial velocity of the H166α line, -20 km/s, found by fitting a gaussian to the emission is in good agreement with optical observations (Georgelin et al., 1970). This result is observed in most low-density HII regions (Pedlar, 1980). The line half power width is 25 km/s with a turbulent velocity $\langle v_t^2 \rangle^{1/2}$ = 16 km/s. The differences between the velocities of the H109α line and the H166α line could be due to the lower velocity resolution (Δv = 5 km/s) of the observations of the H109α line (Wilson et al., 1970). Anyway, relative motion between both regions could exist.

CONCLUSIONS

The H166α recombination line emission is formed in a plasma of low density, $N_e \simeq 11$ cm^{-3}, and moderate electron temperature, $T_e \simeq 4600$ K. The line velocity, v = -20 km/s, of this gas could be representative of the cool neutral gas in the neighbourhood of NGC 6193, since the OH and H_2CO seen in absorption have similar velocities (Whiteoak et al. 1974).

The ionized and neutral region must be spatially close, perhaps as a predominantly neutral regions interspersed with fully ionized clumps. On the other hand the ionized and neutral regions could be widely separated and unrelated, and the ionized gas observed must be present in a large clump. In this case the gas near NGC 6193 is fully ionized possibly heated by the O stars HD 150135/36 which are embedded in it, and is not associated with the neutral gas. Interferometric observations are necessary to make clear which alternative is valid.

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Table 1

Comparison of the parameters of the region at 1.4 Ghz obtained by the author with those obtained by Wilson et al., (1970) at 5 Ghz

Hn α line	$\frac{T_L}{T_c}$	Δv (km/s)	T_e (K)	N_e (cm^{-3})	EM ($pc\ cm^{-6}$)	v (km/s)
* 109	.048	20	9700	3000	4×10^6	-25
166	.022	25	4800	11	2400	-20